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Final Report

DEVELOPMENT OF AIR FORCE FLIGHT SAFETY MODELS

Volume 1

CONTRACT PERFORMANCE SUMMARY

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September 1976

Prepared for

SERVICE ENGINEERING DIVISION
SAN ANTONIO AIR LOGISTICS CENTER
Kelly Air Force Base, Texas

Under Contract F09603-72-A-1132-SA01

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The work performed by ARINC Research Corporation in developing flight safety prediction models for a variety of Air Force aircraft is discussed. This study represented the first broad application of the Flight Safety Prediction Technique developed by ARINC Research Corporation under previous Air Force contracts.

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ABSTRACT

The work performed by ARINC Research Corporation in developing flight safety prediction models for a variety of Air Force aircraft is discussed. This study represented the first broad application of the Flight Safety Prediction Technique developed by *ARINC Research Corporation* under previous Air Force contracts.

SUMMARY

This document is part of a 16-volume report describing the application to specific aircraft types of ARINC Research Corporation's Flight Safety Prediction Technique (FSPT). The technique was developed under previous Air Force contracts. The present effort, undertaken in 1972 under San Antonio Air Logistics Center (SA/ALC) Contract F09603-72-A-1132-SA01, has led to further refinement of the FSPT through its broad application to many different types of aircraft. The flight safety models generated for these aircraft are presented in individual volumes of this report as follows:

Volume	Aircraft	Volume	Aircraft
1	Contract Performance Summary	9	OV-10
2	T-38	10	B-52G, H
3	F-111A, FB-111A	11	C-130E
4	A-7D	12	KC-135
5	F-4D, E; RF-4C	13	C-5A
6	C-141	14	T-39
7	A-37	15	F-15
8	O-2	16	UH-1N Helicopter

This document (Volume 1) provides an overall summary of the contracted effort, and is formatted as follows:

- Section 1 – Introduction. Discusses the background of the flight safety program and discusses general concepts of the FSPT.

- Section 2 – Task Description. Provides an overview of the work accomplished during the contract performance period, and of the methods used to perform the assigned tasks.

- Section 3 – Conclusions and Recommendations. Presents conclusions drawn from the study and recommendations for further application of the FSPT.

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1
INTRODUCTION

1.1 BACKGROUND

In 1965, the Air Force contracted ARINC Research Corporation to study the feasibility of quantifying the significance of specific equipment malfunctions relative to flight safety. The feasibility of a safety-quantification approach, which has subsequently become known as the Flight Safety Prediction Technique (FSPT), was demonstrated and has been further developed and refined in a series of subsequent studies. Table 1-1 provides basic contract information on these studies, and references the ARINC Research reports in which the results appear. Further details on the history of the FSPT may be found in Appendix A, "Formulation of Criticality-Assessment Technique", and Appendix B, "FSPT Documentation Procedures", of each aircraft volume (2-16) of this report series.

The present contract, awarded to ARINC Research in 1972 by the Air Force, directed the application of the FSPT to 15 aircraft types and included a feasibility study for adaptation of the FSPT to rotary-wing aircraft. Since the date of contract issuance, several amendments have been made to the original document. Terms of the original contract and significant amendment provisions are summarized in Table 1-2.

1.2 GENERAL CONCEPTS OF FSPT

The FSPT provides for assessment of the impact on flight safety of the failure of specific items of equipment within an aircraft. In this technique, mathematical modeling procedures are applied for processing aircraft-equipment failure data to yield a quantified index that ranks safety-related problems on the basis of their likelihood of occurrence and the resulting degradation in the aircraft's capability to fly. A detailed explanation of the FSPT process is provided in Appendixes B and C of each aircraft volume (2-16) of the final report.

The above-mentioned ranking factor is termed "criticality", which in its simplest form is the product of the failure probability and flight-safety sensitivity of an equipment. The failure probability inputs are from basic failure-data sources, AFM 66-1 and AFR 65-110. The sensitivity estimates are derived by the following process:

a. Systematic analysis of aircraft functions to determine those essential to flight safety

b. Identification of the hardware required to perform these functions

c. Evaluation of the safety significance of the hardware identified in step b.

TABLE 1-1. HISTORICAL SUMMARY OF FSPT

Subject/Date	Sponsor/Contract Number	Publ. No., Final Report
Feasibility Study, September 1965 to June 1967 (Phase I)	Sacramento Air Material Area (SMNE), Contract AF09(603)62355, SM-67-2	705-01-1-777
Technique Development, October 1967 to July 1968 (Phase II-A)	San Antonio Air Material Area (SANEW), Contract AF09(603)-67-A-0267-SA01	734-01-1-895
Technique Development, July 1968 to July 1969 (Phase II-B)	San Antonio Air Materiel Area (SANEW), Contract F09(603)-68-A-0317-SA01	754-01-1-985 (Revision 1)
FSPT System Documentation for F-4C and T-37 Aircraft, October 1970 to June 1971	San Antonio Air Materiel Area (MMER), Contract F41608-71-C-0576	697-01-1-1118
Development of Air Force Flight Safety Models, June 1972 to September 1976	San Antonio Air Logistics Center (MMER), Contract F09603-72-A-1132-SA01	C54-01-1-1406

The criticality values resulting from this approach provide a relative ranking of all malfunctions with respect to their safety significance. Figure 1-1 is a simplified example of how three equipment items would be ranked on the combined basis of their failure probability and safety sensitivity. Note in this example that item A has the highest failure probability, but because of its low safety-sensitivity value is ranked below item B in criticality.

The criticality ranking can serve many useful purposes, among them:

a. Identifying equipment items whose failure history and application pose a threat to aircraft safety

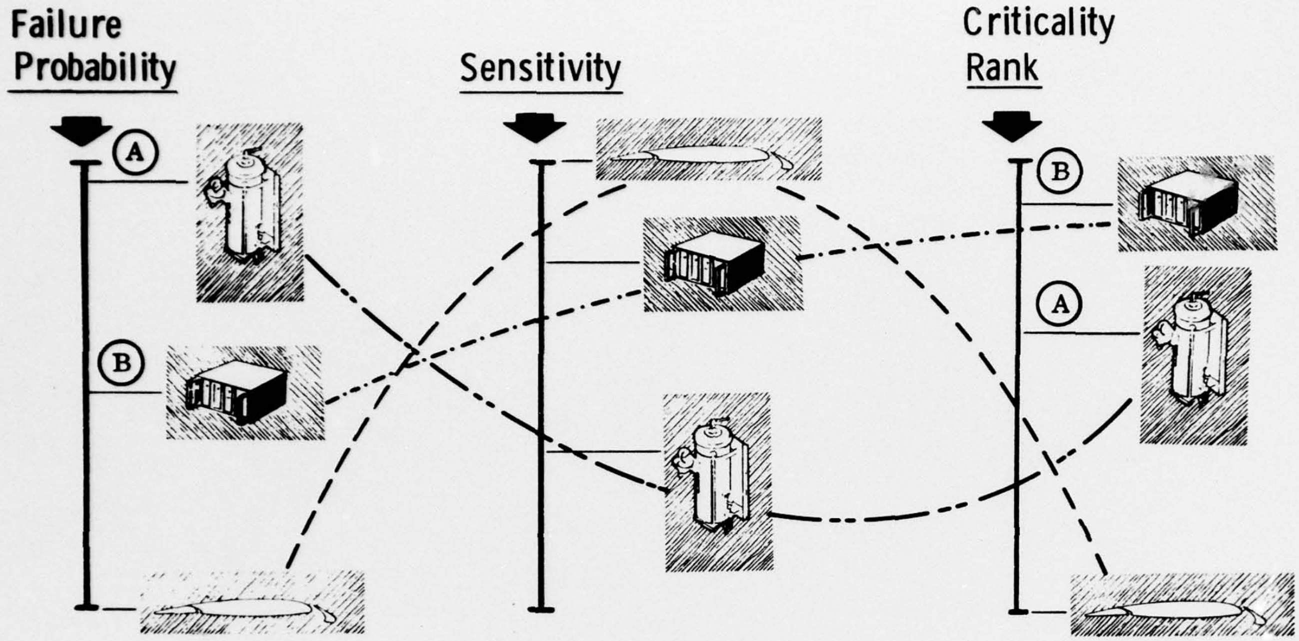
b. Quantifying the degree of threat associated with each equipment item

c. Evaluating and tracking the effectiveness of modifications to an aircraft

d. Assessing safety benefits versus the cost of proposed aircraft modifications, changes in maintenance or flight operations, or alternative aircraft designs.

TABLE 1-2. CONTRACT PROVISIONS

Date/Contract Amendment No.	Aircraft Covered	Systems Responsibility: ARINC Research	Systems Responsibility: Cognizant ALC
June 30, 1972; Basic Contract	C-5 T-38 A-7D F-111 FB-111 C-141 A-37 B-52G B-52H F-4D F-4E RF-4C C-130 Rotary wing feasibility study	Propulsion Info/display Environment Flight control Utilities	Airframe Com/Nav Ground control Landing gear Mission support
Nov. 24, 1972; Amendment 01	Deleted rotary wing feasibility study		
June 23, 1972; Amendment 02	Added following aircraft: O-2 OV-10 KC-135 T-39 F-15	All except landing gear (for newly assigned aircraft)	Landing gear
Nov. 30, 1973; Amendment 04		All except landing gear (all aircraft)	Landing gear
Sept. 16, 1974; Amendment 05	Added rotary wing feasibility study	Deleted airframe system for all aircraft	



CRITICALITY = P X S

Where P = Probability of failure

S = Safety sensitivity; the accident exposure associated with each failure occurrence

Figure 1-1. Example of Criticality Ranking Process

2
TASK DESCRIPTION

The present study had three goals: to develop flight safety models for the previously identified aircraft types, to study the methodology's applicability to rotary wing aircraft, and to extend internal Air Force technical ability to create and utilize aircraft safety models. To achieve these goals, the effort was organized into a series of tasks and subtasks as discussed in this section.

2.1 MODEL DEVELOPMENT

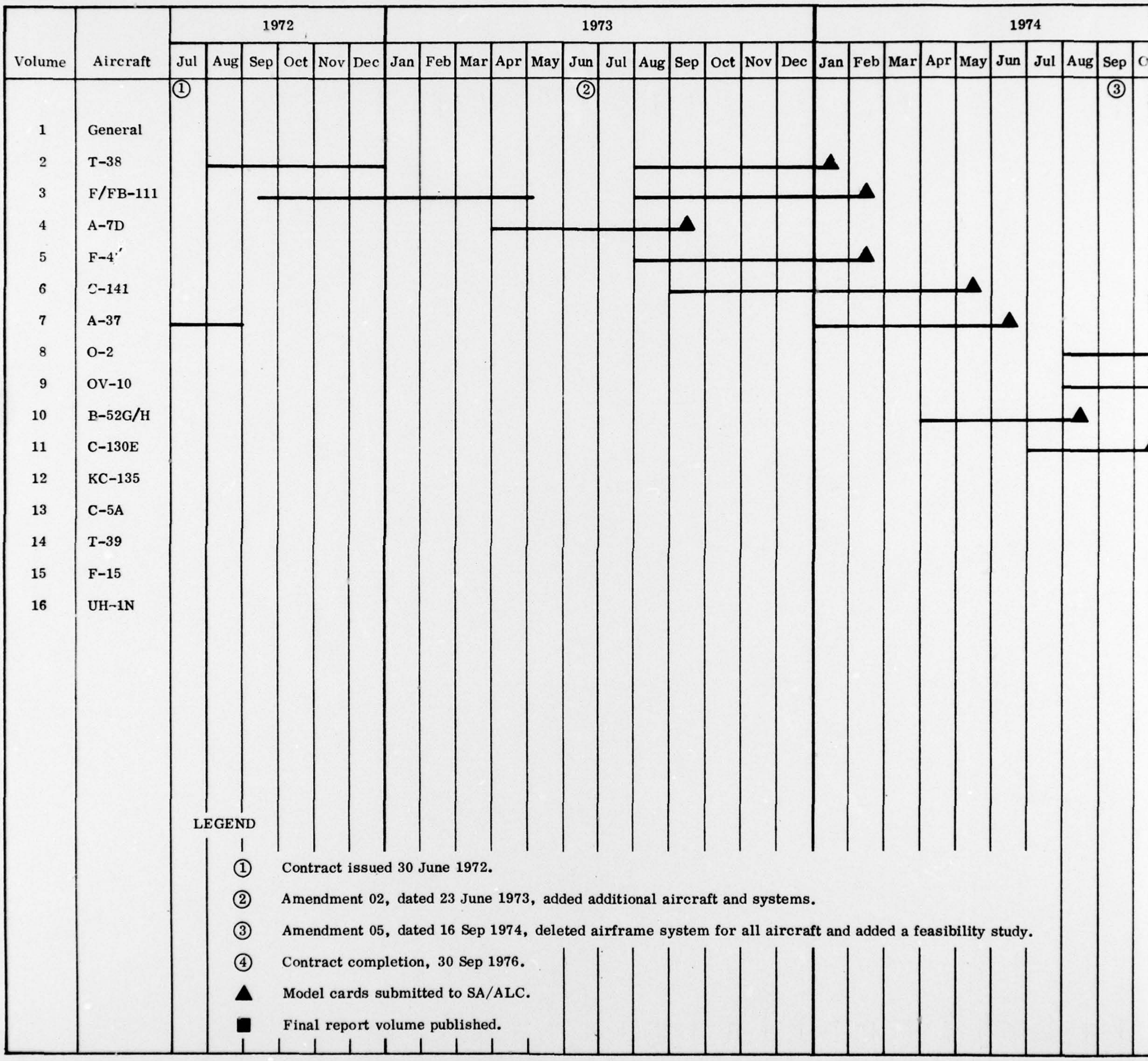
ARINC Research was directed by SA/ALC to apply the FSPT to the development of flight safety models for the aircraft listed in Table 2-1. The sequence and duration of associated activities are illustrated in Figure 2-1. To accommodate the availability of the Air Force documentation and the priorities of participating Air Logistic Centers, scheduled activities were continually changed as appropriate by mutual agreement of SA/ALC and ARINC Research. The referenced figure represents the resulting schedule of activities.

Model development for each aircraft included system functional analysis, functional-diagram preparation, equipment identification and functional correlation, safety-sensitivity assignment, model interface/merging with Air Force-developed portions, and quality control. These tasks are discussed in the following paragraphs.

TABLE 2-1. AIRCRAFT SAFETY MODELS

T-38	B-52G, B-52H
F-111A and FB-111A	C-130E
A-7D	KC-135
F-4D, F-4E and RF-4C	C-5A
C-141	T-39
A-37	F-15
O-2	UH-1N*
OV-10	

*Feasibility study of adaptation of FSPT to rotary wing aircraft.


Volume
Aircraft
1972
1973
1974
Jul Aug Sep Oct Nov Dec
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Jan Feb Mar Apr May Jun Jul Aug Sep
①
②
③
1 General
2 T-38
3 F/FB-111
4 A-7D
5 F-4'
6 C-141
7 A-37
8 O-2
9 OV-10
10 B-52G/H
11 C-130E
12 KC-135
13 C-5A
14 T-39
15 F-15
16 UH-1N
LEGEND
① Contract issued 30 June 1972.
② Amendment 02, dated 23 June 1973, added additional aircraft and systems.
③ Amendment 05, dated 16 Sep 1974, deleted airframe system for all aircraft and added a feasibility study.
④ Contract completion, 30 Sep 1976.
▲ Model cards submitted to SA/ALC.
■ Final report volume published.

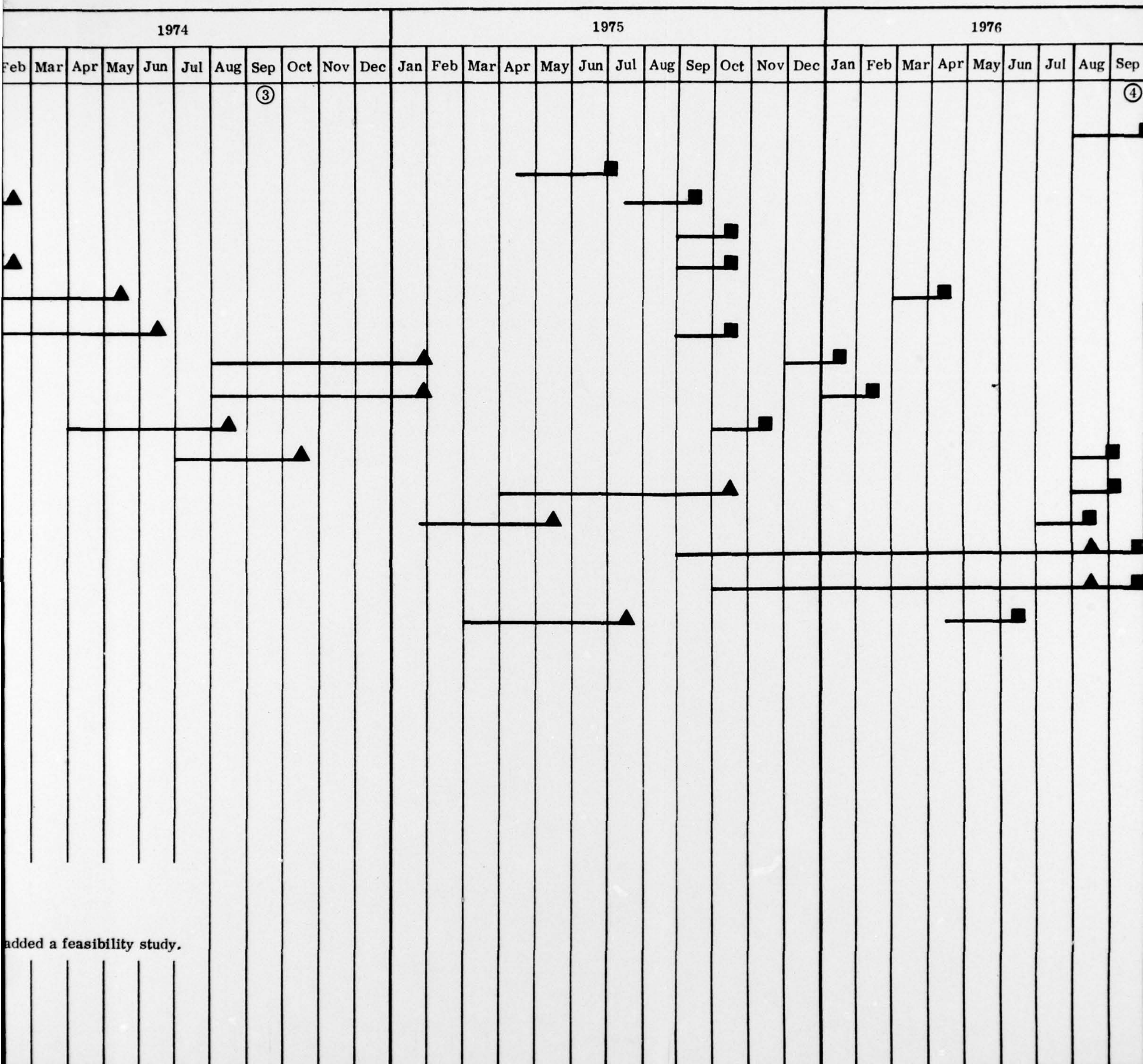


Figure 2-1. Schedule of Contract Activities

2.1.1 Functional Analysis/Diagram Preparation

ARINC Research prepared functional diagrams for all aircraft systems except the landing gear, for which responsibility was assigned to the ALC having control of the specific aircraft. The diagrams, based on a functional analysis of the systems as described by the latest edition of the technical orders and flight manuals supplied by SA/ALC, depict the hierarchical functional relationships of the systems analyzed.

2.1.2 Sensitivity Assignment

For each functional relationship diagrammed, a sensitivity number was assigned. At the upper levels of the functional hierarchy, this value is a measure proportional to the probability that the failure of a function will cause an accident (or an unsafe condition). At the lower functional levels, this number is called a "link dependency", defined as the probability that the loss of a function will result in the loss of a higher function. For further details of the sensitivity assignment process, refer to Sections 2 and 3 and Appendixes B and C of each aircraft volume.

2.1.3 Equipment Identification and Correlation

The equipment required for accomplishing the functions identified in the previous task was determined and correlated with the applicable work unit code (WUC) from WUC manuals supplied by the Air Force. For equipments not assigned WUCs in the manuals, special codes were created (identified by 99xxx) to indicate and account for critical components that the analyst deemed worthy of identification.

2.1.4 Merging of Air Force/ARINC Research Systems

As stated earlier, responsibility for developing that portion of the flight-safety model relating to the landing gear system for each aircraft was assigned to the Air Logistic Center having control over the specific aircraft. During model development, close coordination was maintained between ARINC Research and the designated ALC to ensure compatibility between the separately developed portions of the model. Following completion of work by the ALC, all systems were reviewed for compatibility, interface connections were made, and the systems were merged to provide a complete model.

2.1.5 Documentation Submittal

The functional relationships and associated sensitivities were documented in a form suitable for machine processing in the "GO-95" automatic data processing system at SA/ALC. This requirement was met by developing a standardized format for coding and keypunching of the required data elements.

Following keypunch, quality reviews of the documentation were conducted by a team of ARINC Research analysts; corrections were made where necessary; and the completed decks, together with functional diagrams, were forwarded to SA/ALC for computer processing.

2.1.6 Quality Control

To ensure a product of uniformly high quality, stringent quality control procedures were applied throughout the model development effort. Some of the most important elements of this QC program are discussed in the following paragraphs.

2.1.6.1 System Organization and Sensitivity Standard

Early in the model development program, an unofficial "System Organization and Sensitivity Standard" was compiled to provide a baseline document from which all models were constructed. From this standard, top-level and major functions of a "typical" aircraft were diagrammed, and sensitivity values were assigned for each. Explanations for system organization and sensitivity assignments were provided in accompanying text.

2.1.6.2 Group Quality Reviews

At various critical points in the modeling process, group reviews were conducted by a team of ARINC Research engineers and analysts as part of the quality control program. These reviews were held at the completion of model development for each major system, and again upon integration of the individual systems into a complete model.

During the initial review, the subject system model was analyzed for accuracy, completeness, and conformity with established standards and procedures. Functional diagrams and coding sheets were checked against appropriate Air Force technical manuals to validate the analytical approach. Equipment required to perform each function was identified and correlated with the appropriate WUC. Sensitivity and link dependency values were examined and adjusted as required. After keypunch verification, each card was manually checked against the original coding sheet and functional diagram.

In the second review, integration of the individual systems was the primary concern. Interface connections with appropriate sensitivity values were verified and changed as necessary. A listing of the cards was obtained, and each functional link was again compared with the functional diagrams before submission to SA/ALC for computer processing.

2.1.6.3 Computer Edit

Each functional card deck received by SA/ALC was submitted to a computer editing program that checked for "broken" functional links, duplicate cards, and other format or logic errors. Errors so identified were corrected, and the deck was then ready for further computer processing.

2.1.6.4 Test Run

After computer editing, aircraft failure data and provisory-factor values obtained from the appropriate ALC were processed with the input deck supplied by ARINC Research to produce a criticality printout. This printout was reviewed for "reasonableness" by ARINC Research, SA/ALC, and the ALC responsible for the aircraft (of other than SA/ALC). When problems appeared, the model was reviewed for correctness and changes made if errors were found.

2.1.6.5 Final Correlation

Before publication of the final report for each aircraft model, a final quality control check was conducted to ensure that all required changes had been incorporated, and that the functional diagrams, card listings, and input card decks were fully correlated.

2.2 FEASIBILITY STUDY

The feasibility of applying the Flight Safety Prediction Technique to rotary wing aircraft was demonstrated through its application to the UH-1N helicopter. Results of this study, presented in Volume 16 of this final report, are summarized below.

In general, it was found that the model developed for fixed-wing aircraft was applicable to helicopters without change to the basic mathematical structure or computer process. Preliminary modifications to the FSPT to accommodate rotary wing aircraft included:

a. Redefinition of certain upper-level functions in accordance with the operation of rotary-wing systems.

b. Redefinition of flight phases to conform with rotary-wing mission profiles.

c. Review of sensitivity assignments in light of autorotative and "land-most-anywhere" criteria.

2.3 USAF/ARINC RESEARCH COORDINATION

The Air Force and ARINC Research activities in the model development program were coordinated as described in the following paragraphs.

2.3.1 Training Program

To assure compatibility of the safety-model segments produced by the cognizant ALCs and ARINC Research, the Corporation conducted training sessions early in the program. Informal instructional material described the general philosophy and criteria of the FSPT methodology, and included sample functional diagrams and applicable keypunch coding instructions.

The training sessions familiarized Air Force personnel with the techniques necessary for completing their portions of the flight safety model. These seminars included individual and group construction of sample system diagrams, completion of coding sheets, and assignment of sensitivity and link-dependency values.

2.3.2 Coordination Activities

The Service Engineering Division of SA/ALC was designated as the controlling office and primary contact between the Air Force and ARINC Research. This office was responsible for general contract administration, product quality control, computer processing, and coordination between ARINC Research and participating Air Logistics Centers.

Throughout the contract period, close liaison was maintained and frequent meetings scheduled between ARINC Research, SA/ALC and other participating ALCs to ensure compatibility of the model development effort by each organization.

2.4 REPORT PREPARATION

The reports required by this contract included monthly status letters and a 16-volume final report.

The monthly letter reports, covering the status of the contracted work, were submitted to the designated contact office at SA/ALC. The reports summarized the work performed during the month, problem areas, and ARINC Research/Air Force agreements on problem resolutions.

The final report has been prepared in 16 volumes. Volume 1 provides an overall summary of the contracted effort, while the remaining volumes are dedicated to specific aircraft. These volumes were issued periodically, as indicated in Table 2-2.

The aircraft volumes (2-16) were designed to provide a concise handbook for each aircraft model. Each volume contains a brief description of the FSPT, model functional diagrams, and a complete card listing for the specific aircraft.

TABLE 2-2. FINAL REPORT VOLUMES

Volume	Subject	Date Published
1	Contract Summary	September 1976
2	T-38	June 1975
3	F-111A, FB-111A	September 1975
4	A-7D	October 1975
5	F-4D, F-4E, RF-4C	October 1975
6	C-141	April 1976
7	A-37	October 1975
8	O-2	January 1976
9	OV-10	February 1976
10	B-52G, B-52H	November 1975
11	C-130E	September 1976
12	KC-135	September 1976
13	C-5A	August 1976
14	T-39	September 1976
15	F-15	September 1976
16	UH-1N Feasibility Study	June 1976

3
CONCLUSIONS AND RECOMMENDATIONS

3.1 CONCLUSIONS

As a result of the development of flight safety models under this effort, it is concluded that:

a. The FSPT can be adapted to a wide variety of aircraft types, including attack, bomber, transport, observation, trainer, tanker, fighter, and reconnaissance configurations.

b. The FSPT developed for fixed wing aircraft can be applied to rotary wing aircraft without change to the basic mathematical structure, computer processing, or data requirements. Only minor changes in the original FSPT are required to accommodate rotary wing system operation and mission profiles.

c. Changes to aircraft system configurations will occur, and impact on the accuracy of the safety models. Therefore the models must be maintained in an accurate and current status.

3.2 RECOMMENDATIONS

The following recommendations are offered:

a. Flight safety models for the remaining Air Force inventory should be developed, including but not limited to the A-10, F-5, F-111D, F-111E, F-111F, C-130A, and C-130D aircraft.

b. A study should be conducted to investigate and evaluate the methods and procedures for creating an FSPT analysis capability for preoperational aircraft.

c. Flight safety models for the Air Force inventory of rotary-wing aircraft should be developed.

d. The material in each flight safety volume should be maintained accurate and current to obtain maximum benefits from the model.